Stabilizing Global Temperature Through a Fuzzy Control on CO_2 Emissions

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Abstract: In this research, we generated a fuzzy control of carbon emissions that acts increasing or decreasing the representative concentration pathway emissions proposed by the IPCC, in order to obtain a CO_2 path that would stabilize the global average surface temperature to a desired level. We used a simple linear climate model that is driven primary by the Carbon emissions. We made simulations under the four RCPs activating the control at different times, which give us a broad knowledge on when is possible to stabilize the temperature, based in the current emissions path. We conclude that taking action earlier (via fuzzy control) will lead not only to reach stabilization, but also, in some cases, to have economic growth allowing to increase emissions at some points in time. Activating the control very late will initiate an oscillation on temperature which will include not only a reduction of emissions but also a necessary anthropogenic net carbon sequestration. This instrument is a common ground where specialists in diverse areas of climate change could contribute in order to set the parameters that we should explore and simulate so that the we can make the best decisions.

1 INTRODUCTION

The most important Climate Change indicator and driver is the global average surface temperature which had already risen by about 0.7°C from pre-industrial levels. In the United Nations Framework Convention on Climate Change, COP16, the parties agreed that the future global warming relative change should be limited to below 2.0°C (King, 2011).

Since the Cancun agreements, more scientific analysis had been done in order to estimate the chance to constrain the warming, according to Rogelj et al. (2009) the national emissions targets of developed countries would need to be adjusted in order to accomplish the agreement.

It is very important to identify the windows of opportunity for action where mitigation cost is less, Parry and colleagues assumed different emission peaks and the correspondent percentage of cuts that would need to be made in order to avoid the most serious global impacts (Parry et al., 2008).

This work is an improved version of a fuzzy control of emissions that computes the amount of Gt of CO_2 increment or decrement that would need to be made in order to stabilize the temperature to a desired level, using an inference system that evaluates the closeness of the actual temperature to the target temperature (Martinez-Lopez and Gay-Garcia, 2011). Fuzzy controllers had been largely used to achieve system's goals in uncertain environments such as transportation, manufacturing and networked embedded systems (Tong, 1977), furthermore, fuzzy controllers had been implemented to stabilize the climate on greenhouses (Javadikia et al., 2009), which help us to sustain our effort of extrapolation to the global temperature.

2 TEMPERATURE SIMULATION

We used the simple climate model that Tahvonen and colleagues proposed (Tahvonen et al., 1994) where the change in atmospheric Carbon concentration (C) depends on the emission (E) and in the Carbon concentration of the system, equation (1). The change global average surface temperature (T) depends on the atmospheric Carbon Concentration and on the system temperature itself, equation (2).

$$\frac{dC(t)}{dt} = -\sigma C(t) + \beta E(t) \qquad (1)$$

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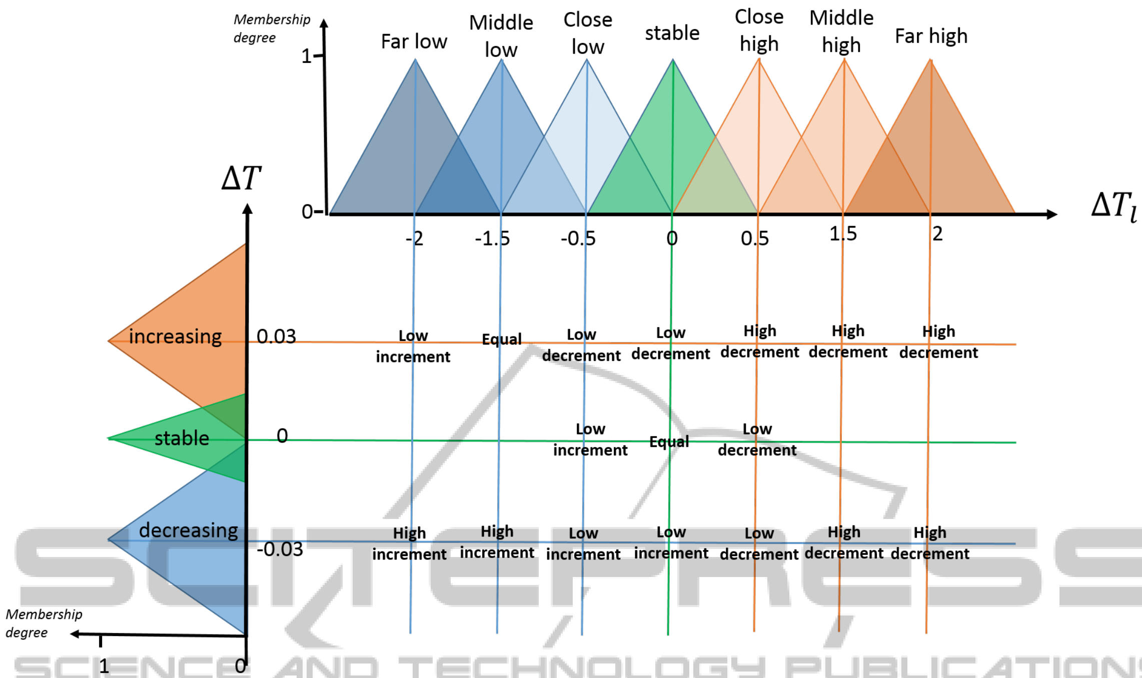

Figure 1: Fuzzy sets and Inference Rules. Top: Closeness to desired temperature, left: change in temperature, inside: change in carbon emissions. Important note: the fuzzy sets have gaussian shape, the triangules showed here are just used to simplify the illustration.

$$\frac{dT(t)}{dt} = -\alpha T(t) + \mu C(t) \quad (2)$$

The constants are $\sigma = 0.018/year$, $\alpha = 0.03$, $\mu = 0.00045$ (Tahvonen et al., 1994) and $\beta = 0.47\,ppm/GtC$ (Maier-Reimer and Hasselman, 1987), the atmospheric carbon concentration and the global average surface temperature in the equations are taken as the anomalies relative to 1959. In our simulations, the carbon concentration levels (Boden et al., 2013) and temperature (NASA, 2014) on 2010, are default settings. The user should set the desired temperature of stabilization, and the climate model will start computing with the emissions data of one of the Representative Concentration Pathways (RCP) (Moss et al., 2007) that IPCC proposes.

The control input variables are the closeness of the actual temperature to the target temperature, and the temperature change, relative to the previous year. The control output is the change in the carbon emissions that would need to be made relative to the previous year emissions in order to drive the temperature to the desired stabilization level.

Whenever the control is activated, the emissions will totally depend on the control and the RCP emissions data will no longer be followed.

3 FUZZY CONTROL

The input variables of the fuzzy control are the closeness to the desired temperature and the temperature change relative to the previous year. As it can be seen in Figure 1, the domain of both variables is divided into fuzzy sets that follow a linguistic description, the closeness to temperature domain is divided into 7 fuzzy sets (far low, middle low, close low, desired, close high, middle high and far high) which represent how close is the actual temperature to the desired one. The domain of the temperature change relative to the previous year is divided into 3 fuzzy sets: increasing, decreasing, stable.

The control works with inference rules (Figure 1) that relate the input variables to the change in carbon emissions that would need to be made, this domain is divided in 5 fuzzy sets, linguistically described as: high increment, low increment, equal, low decrement, high decrement.

The range of action for the input variables was selected having in mind the 2 degrees agreement and the maximum and minimum change in average temperature from year to year. The range for the output variable was selected using the maximum and minimum change in carbon emissions proposed by the IPCC in the RCPs.

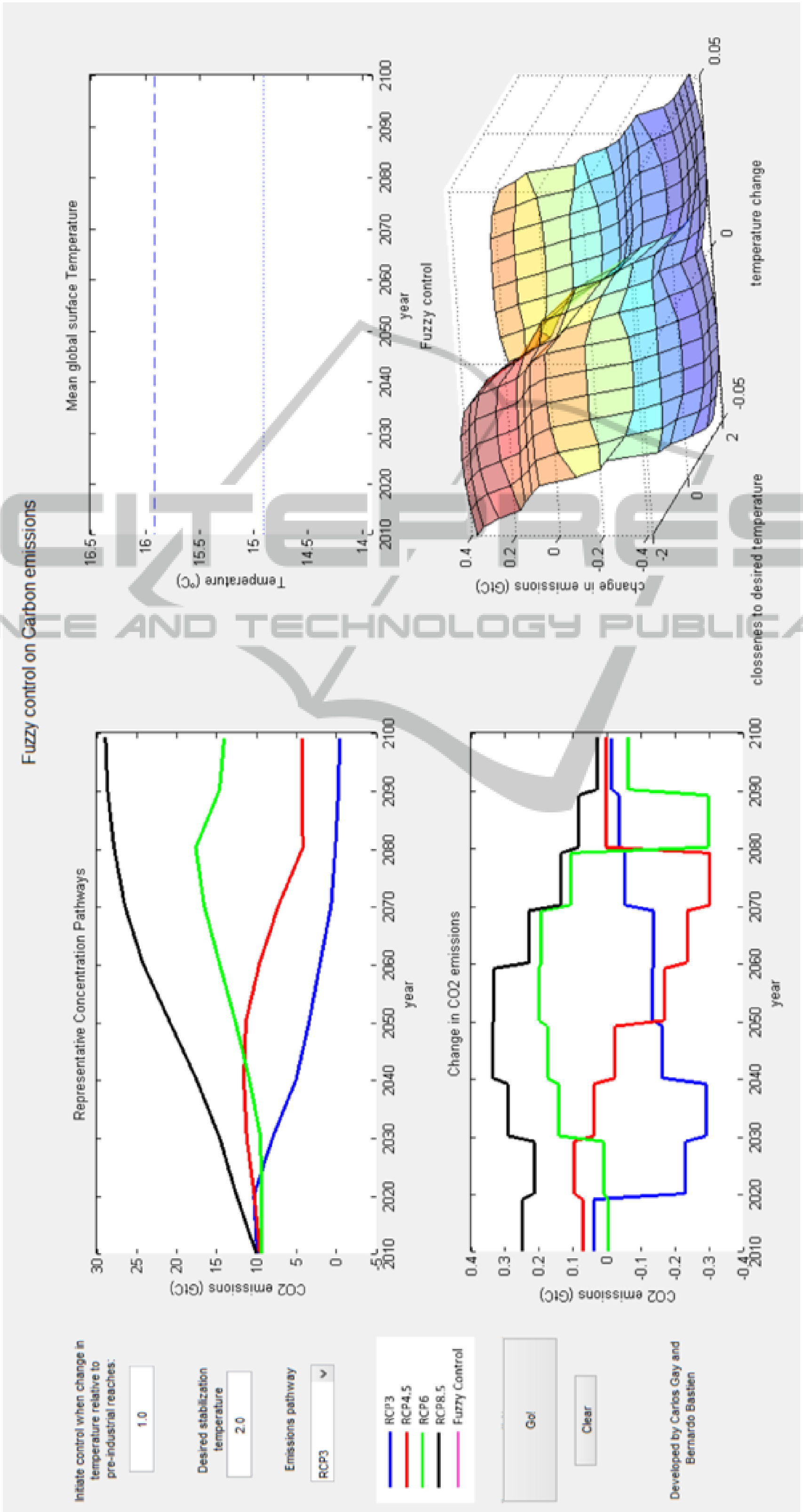

Figure 2: Graphical User interface simulator, more information in Section 4.

4 GRAPHICAL USER INTERFACE

The principal result of this work is an interactive Graphical User Interface (GUI) generated in MATLAB (Figure 2) that simulates the temperature and show the principal results. At the left side there are three user inputs, the activation temperature, the desired stabilization temperature and the emissions pathway that the simulation will follow until the control is activated.

The top left graphic shows the four possible scenarios (RCPs) that the user can choose, the bottom left panel shows the change in carbon emissions of those scenarios. At the top right panel are shown two lines, corresponding to the desired temperature (dashed line) and the activation temperature (dotted line). The rules surface, associated to the inference and rules of the control is shown in the bottom right side. Whenever the button ”Go” is pushed the simulation will start and a magenta line (or dot) will be draw on the four graphics, showing the actual path that the simulation is taking.

5 EXPERIMENTS

We set the activation temperature at 1°C and the stabilization temperature at 2°C, then we simulate under the four RCPs and we obtain the results of Figure 3 and 4. As we can see, the temperature paths are quite different, under RCP3 the stabilization is reached by the year 2200, and it has a local stabilization from 2050 to 2100. The other projections don’t have any 50-year local stabilization and is not guaranteed the stabilization at year 2200. Despite of the great difference on temperature projections, the change in carbon emissions (%) are very similar, which could indicate that the actions taken in the incoming years will be key in the long term global warming.

Furthermore, we ran the model stabilizing at 2°C, following the four RCPs and activating the control at 1°C, 1.5°C, 1.8°C and 2°C. The results are shown on Figure 5.

6 DISCUSSION

6.1 RCP3 Scenario

Following the most optimistic scenario is not the best option in terms of economic growth and temperature stabilization, for a few reasons. As we can see

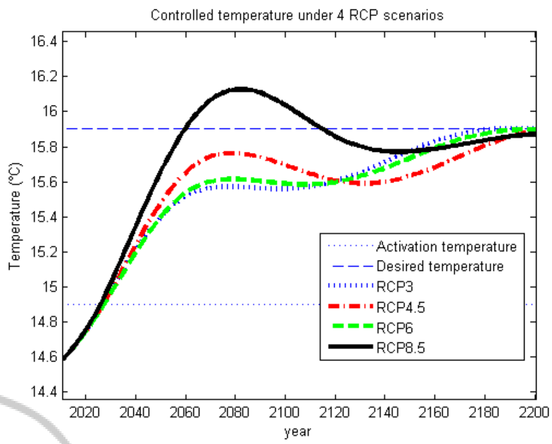

Figure 3: Temperature projected under the RCP scenarios, until activation temperature is reached (1°C from pre-industrial. Stabilization temperature: 2°C. Activation year: 2026 for RCP3,

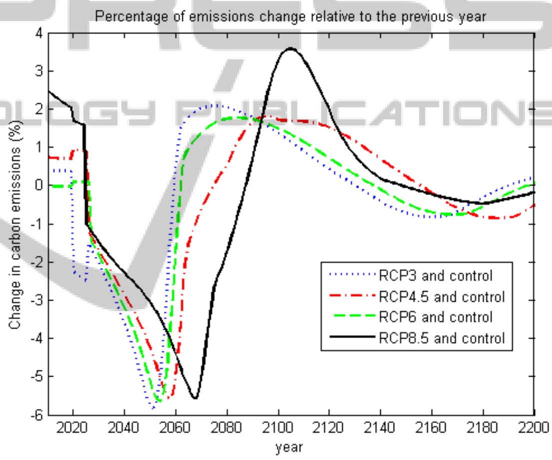

Figure 4: Percentage of emissions that would need to change relative to the previous year.

in Figure 5: Row1, Column1 (R1C1), the emissions control that activates at 1°C and 1.5°C stabilize the temperature at 2°C (15.9°C) and in R1C2 is shown that an earlier control lead to emit more carbon than the suggested by the scenario. The activation temperatures set in 1.8°C and 2°C do not fire the control because under the RCP3 scenario the temperature never reaches those numbers, in R1C2 we can see that the change in carbon emissions relative to the previous year is vertical for those activation temperatures, this is because the change in emissions indeterminate, which means that the emissions cross the zero and carbon sequestration is supposed.

6.2 RCP4.5 Scenario

In R2C1 is shown that all temperatures could reach stabilization but an early control activation avoids

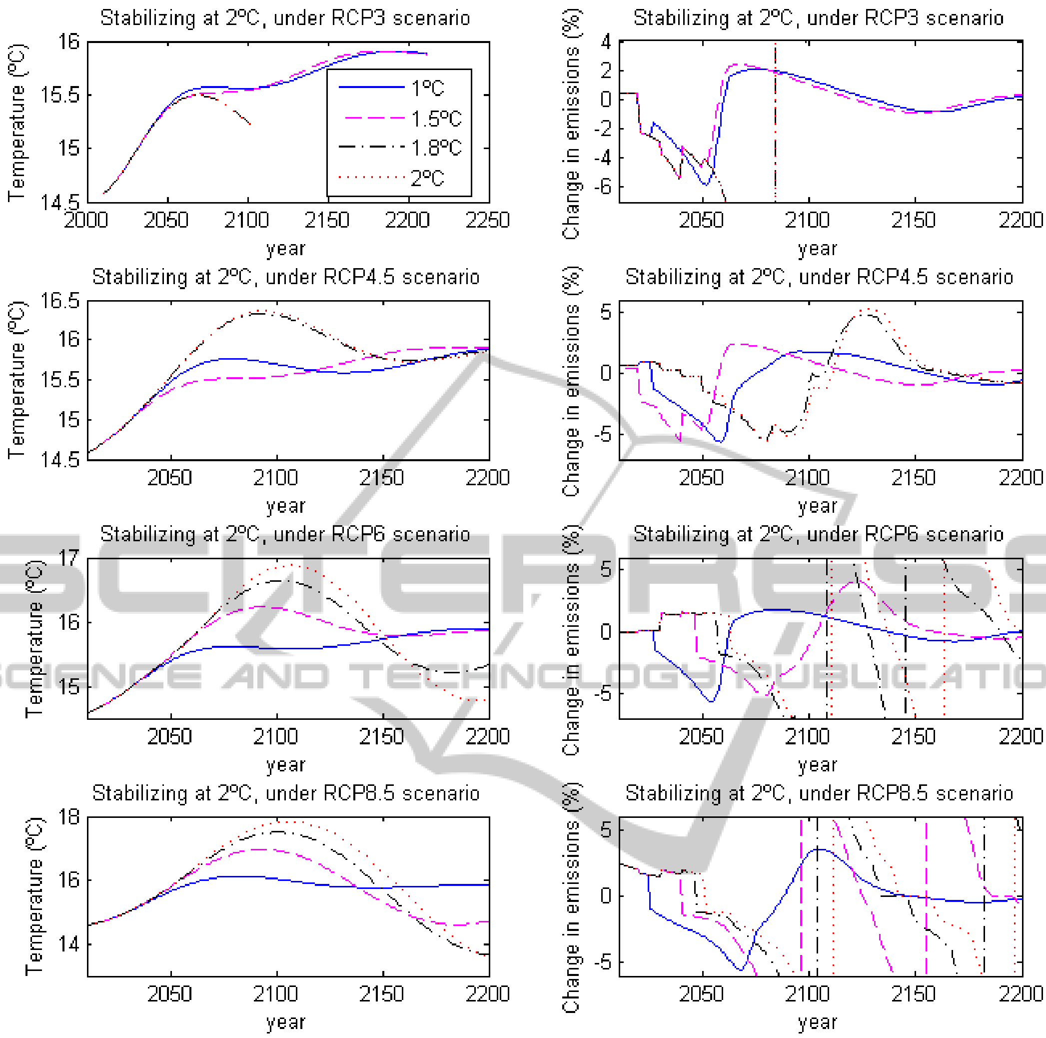

Figure 5: Simulations under RCP3, RCP4.5, RCP6 and RCP8. The control is activated at 1°C, 1.5°C, 1.8°C and 2°C, each row of plots represents an RCP (R1:RCP3 and so on). The first column (C1) is for temperature and the second column (C2) is for their respective change in emissions

temperature overshooting. We can also observe in R2C2 that an earlier activation the negative peak is reached earlier but the amplitude between the negative and the positive peaks is less, which means that technologies and global policies wouldn't have to change drastically in a few years.

6.3 RCP6 Scenario

In R3C2 of Figure 5, is shown that the temperture stabilization is reached only when the control is activated at 1°C and 1.5°C (with overshooting), otherwise during the first 200 years the temperature will acquire an oscillatory behaviour, moreover in R3C2 we can see that activating the control at 1.8°C and 2°C would imply carbon sequestration methods.

6.4 RCP8.5 Scenario

If the emissions path follow the worst scenario in the following years, a temperature stabilization (with overshooting) could be reached only if the control activates very early, at 1°C (R4C1). Otherwise the temperature would oscillate and carbon sequestration would be needed (R4C2).

7 CONCLUSIONS

With the results obtained in the simulations we can take decisions by answering the following question: Under which scenario we are developing? So then, it is possible to observe at what temperature we should activate the control in order to stabilize the temperature. There are some cases where the control activation leads to increment the emissions immediately, which can give us an idea that this kind of control can also lead to economic growth.

This simulation tool with the fuzzy control proposed is a very powerful instrument in climate change policy and international agreements. The configuration options allow us to project under certain circumstances that answer the questions: When are we taking action? and, What is our goal stabilization temperature?

The results will give us not just how many GtC we should decrease or increase every year, but also the percentage of emissions relative to the previous year, which could give us an idea of how much it will cost us (Figure 4).

This instrument is a common ground where specialists in diverse areas of climate change could contribute in order to set the parameters that we should explore and simulate so that the we can make the best decisions.

In future work, we seek to not only project the amount of carbon emissions that should be changed, but also the amount which each country should contribute to accomplish the goal, based on a fuzzy inference system that asses every country possibilities ans responsibility.

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